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GAMMA-RAY OBSERVATIONS OF SN 1987A FROM ANTARCTICA

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ABSTRACT

We report the observation of gamma-ray lines from the direction of supernova 1987A with a germanium detector flown on a high-altitude balloon platform over Antarctica in 1988 January. Gamma rays at 844.1 ± 1.0 and 1239.9 ± 1.5 keV with fluxes $2.3 \pm 2.0 \times 10^{-3}$ and $2.1 \pm 1.0 \times 10^{-3}$ photons cm^{-2} s^{-1}, respectively, are attributed to the radioactive decay of ^{56}Co. Errors quoted do not include possible systematic effects.

Subject headings: gamma-rays: general — stars: supernovae

I. INTRODUCTION

In the present communication we report some of the results from the flight of the GRAD (Gamma-Ray Advanced Detector) Supernova Observer over Antarctica. Launched on a 3.3×10^5 m^3 balloon from Williams Field near McMurdo Station, Antarctica on 1988 January 8, 0015 UT, the instrument reached and maintained a float altitude of 36.6 km, following the 78° S parallel eastward until it was brought down some 320 km east of Vostok on 1988 January 10, 2345 UT and recovered on 1988 January 14.

II. INSTRUMENT

The gamma-ray spectrometer has been described in detail elsewhere (Rester *et al.* 1986). The central element is a 135 cm^3, *n*-type germanium detector with an energy resolution of 2.3 keV (full width at half-maximum [FWHM] at 1173 keV) in flight configuration. It is enclosed in active shielding of bismuth germanate having an aperture with a half-angle width of 27°. The shield has side walls 4.5 cm thick as well as 10 cm of active material behind the *n*-Ge detector. A 0.3 cm thick plastic scintillator over the aperture provides additional active shielding against charged particles. Special care was taken in the reduction of the amount of passive material inside the shield and of iron in the entire system. An overall background suppression factor of better than 20 over the energy range (700–3000 keV) was measured at altitude with the shield switched off and on. The instrument operated with azimuthal pointing only; with a fixed detector zenith angle of 21°, the supernova-detector angle varied only ±14° about that value while pointed at the supernova. A detector pointing cycle consisted of 1 hr pointed on the supernova followed by 55 minutes pointed off the supernova with data accumulated around the compass in 11 30° steps of 5 minutes each. Data were taken in 30 s time bins over the energy range from 50 keV to 10 MeV with three overlapping 4096 channel analog-to-digital converters.

III. OBSERVATIONS AND ANALYSIS

A failure of a 1200 V power supply during the first day of the flight disabled half of the BGO shield, decreasing the background suppression from a factor of 20 to 10 and introducing unwanted contaminant peaks into the spectra. For this reason we have restricted the data analyzed for the present report to events recorded only while the instrument was fully functional. These include a 3.5 hr set of "on-supernova" data accumulated while the line of sight to the supernova was within 18° of the detector axis and a 1.9 hr set of "off-supernova" data taken while it was at least 21° off axis. Experimental spectral segments, normalized to counts per 10^4 s, are shown for the 847 keV and 1238 keV energy regions in Figures 1 and 2, respectively.

Data analysis has been performed with the computer code ROBFIT (Coldwell 1986) which represents the shapes of gamma-ray lines, background continua, and other features with combinations of spline functions. These shapes are determined by fitting to experimentally determined response functions which are then used in a pattern recognition algorithm for spectral analysis. In the present case patterns were defined for annihilation radiation, unbroadened gamma-ray peaks from local interactions, ramp-shaped peaks arising from neutron inelastic scattering in the germanium detector, and broadened peaks as models of possible supernova lines. In the analysis of a spectrum, the background continuum for the entire 4096 channels of data was fitted, and peaks were sequentially added where required to reduce the largest remaining residuals. Background and peaks were adjusted together at each step until a χ^2 minimization was attained, both locally and globally. No *a priori* constraints were imposed on the

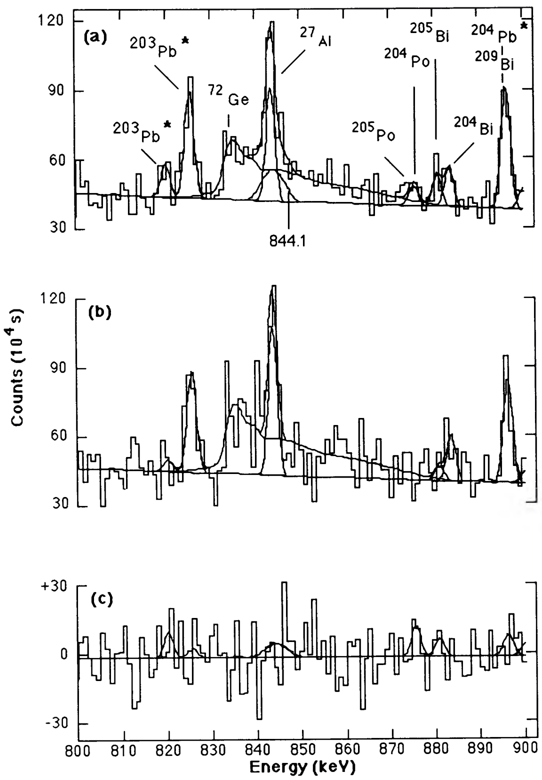

FIG. 1.—The 847 keV region of the 1988 January 8 gamma-ray spectra taken over Antarctica. Shown in the panels are (*a*) the on-supernova spectrum, (*b*) the off-supernova spectrum, and (*c*) the difference spectrum resulting from the time-normalized subtraction of one from the other. Peaks labeled by isotope are locally generated background lines.

widths or energies of the supernova peaks; the computer was free to fit these as required for minimization.

We have treated the background problem in the following manner. First, the list of peak channel numbers and strengths found in the on-supernova spectrum were supplied as starting data to the code, which was then constrained to hold peak locations constant but allowed to adjust strengths as required for error minimization. By this procedure, estimates of line strengths in the off-supernova spectrum were obtained and subsequently subtracted from the on-supernova results.

The results of the peak fitting process are shown in Figures 1*a*, 1*b*, 2*a*, and 2*b*. The 1239.9 keV line appears clearly in the on-supernova spectrum, but not in the off-supernova spectrum. Although the 844.1 keV line is buried beneath background lines from the germanium detector and aluminum housing, it is found by deconvolution of the spectrum in the on-supernova, but not the off-supernova spectrum. A peak of the same width as the 1239.9 keV line is found in the on-supernova spectrum at 1222.1 keV, but appears in the off-supernova spectrum as well. The evidence from the present data set for the connection of this feature with the supernova decay is therefore inconclusive.

In the determination of the measured count rates of supernova events, the fitted peak counts for the lines in the on- and off-supernova spectra were first determined separately and then subtracted to provide a net supernova line count rate. These count rates are listed in the upper part of Table 1 under the heading "Present Background Subtraction Method." These rates were then converted to the net fluxes set in boldface in the table.

For comparison we have used the traditional method of subtracting the off-supernova from the on-supernova spectrum and then fitting the remainder "source" spectrum. Segments of interest are shown in Figures 2*c* and 3*c*. In the present case we have started the analysis with the peaks known to exist in the on-supernova spectrum and added or subtracted peaks as required for minimization. This approach has the disadvantage that valid data are thrown away with the direct subtraction, as there is some leakage through the shield. The two methods are seen to yield comparable results, as shown at the bottom row in Table 1. We have adopted the present method in order to take advantage of all available data.

IV. DISCUSSION OF RESULTS

The results of the present measurements are listed in Table 1. Within the statistical limitations of the restricted data set as defined above, we confirm our preliminary report (Rester *et al.* 1988*a*, *b*) of observation of lines at 844.1 keV and 1239 keV. There is a discrepancy in the locations of the centroids of these two peaks, the one appearing somewhat redshifted but the other, slightly blueshifted. We attempted to fit the data in the 847 keV region with a peak at 847.9 keV having a -383 km s^{-1} Doppler shift consistent with that of the 1239.9 keV peak, but found that the fit to the data was significantly degraded. This could be explained by the existence of a strongly redshifted component analogous to that tentatively reported at 1222.1 keV. A possible (836–848 keV) doublet of peaks with

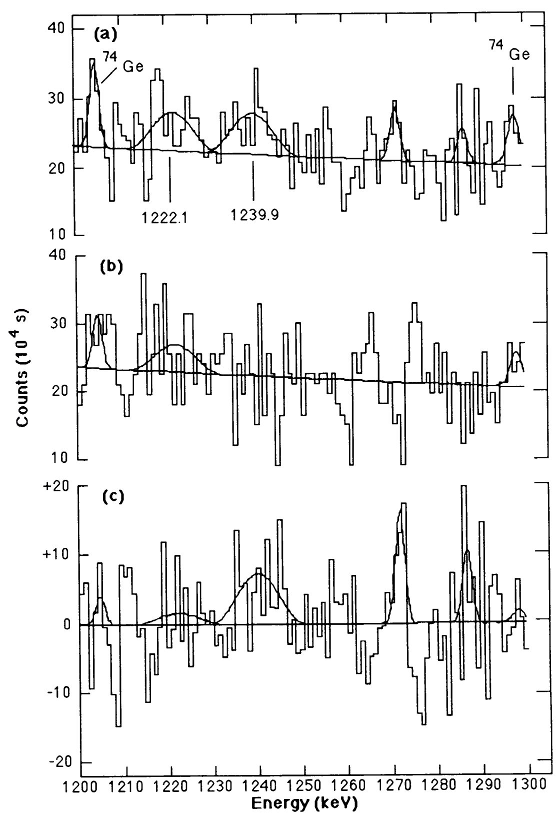

FIG. 2.—The 1238 keV region of the same spectra. Shown in the panels are (*a*) the on-supernova spectrum, (*b*) the off-supernova spectrum, and (*c*) the difference spectrum resulting from the time-normalized subtraction of one from the other. Peaks labeled by isotope are locally generated background lines. An apparent peak at 1270 keV in the difference spectrum is a result of statistical fluctuations in the generating spectra.

TABLE 1

GAMMA-RAY LINES IDENTIFIED IN THE GRAD EXPERIMENT[a]

Parameter		Line Identification		
	Energy (keV) =	844.1 ± 1.0	1222.1 ± 1.6	1239.9 ± 1.5
	FWHM (keV) =	6.0 ± 2.6	10.1 ± 3.6	10.4 ± 3.4
System Parameters:				
Transmission factor		0.63	0.68	0.68
Effective area (cm^2)		5.8 ± 0.3	4.4 ± 0.3	4.4 ± 0.3
Present Background Subtraction Method				
On supernova counts ($\times 10^{-3}$ s^{-1})		8.4 ± 4.5	5.9 ± 2.0	6.4 ± 2.0
Off supernova counts ($\times 10^{-3}$ s^{-1})		0.0 ± 5.5	4.3 ± 2.4	0.0 ± 2.2
Net on-off counts ($\times 10^{-3}$ s^{-1})		8.4 ± 7.1	1.6 ± 3.1	6.4 ± 3.0
Net supernova flux ($\times 10^{-3}$ photons cm^{-2} s^{-1})		**2.3 ± 2.0**	**0.5 ± 1.0**	**2.1 ± 1.0**
Direct Background Subtraction Method				
Source counts ($\times 10^{-3}$ s^{-1})		3.7 ± 6.4	1.7 ± 2.9	7.9 ± 2.8
Supernova flux ($\times 10^{-3}$ photons cm^{-2} s^{-1})		1.0 ± 1.8	0.6 ± 1.0	2.6 ± 0.9

[a] Count rates in the lines were determined from computer-fitted peaks. Atmospheric transmission factors were calculated at an average zenith angle of 21° from a geometric altitude of 34.64 km, referenced to the 1976 Standard Atmosphere, yielding a column density of 6.19 g cm^{-2}. Line fluxes determined by direct background subtraction are shown for comparison of methods; adopted fluxes are boldface.

widths comparable to those at 1222.1 and 1239.9 keV would not be clearly separated and would have a centroid at about 842 keV to 844 keV, as observed in the present work. Resolution of the question will require more accurate definition of the background features in the 847 keV region, in particular the exact structure of the ^{72}Ge neutron inelastic scattering peak.

On the basis of the present limited data set, we can neither confirm nor rule out the feature at 1222.1 keV. The evidence in our full data set, including data in which our BGO shield was only half operational, is more clearly supportive. However, the use of the full data set leaves open the possibility that the malfunctioning BGO shield, by allowing the leakage of spurious events into the spectra, might be responsible for this feature. We are continuing to investigate the question.

Two previous balloon flights of high-resolution gamma-ray spectrometers have detected line emission from SN 1987A, the first (Sandie *et al.* 1988) on 1987 October 29, and the second (Mahoney *et al.* 1988) on 1987 December 6. Our result is in agreement with the values of Mahoney *et al.* (1988) for the 1239 keV line flux, but we find that our 844.1 keV flux appears to be higher than their reported value of $0.5 \pm 0.7 \times 10^{-3}$ photons cm^{-2} s^{-1}. Sandie *et al.* (1988) report an 847 keV flux of $1.0 \pm 0.28 \times 10^{-3}$ photons cm^{-2} s^{-1}, but no clear structure indicating a line at 1238 keV. During the period from 1988 January 8 to February 4, the *Solar Maximum Mission* (*SMM*) Gamma-Ray Spectrometer Group measured fluxes of $0.39 \pm 0.42 \times 10^{-3}$ and $0.22 \pm 0.36 \times 10^{-3}$ photons cm^{-2} s^{-1} at 847 keV and 1239 keV, respectively (Matz, Share, and Chupp 1988). These fluxes are the lowest reported by that group since 1987 August 2 and are considerably below ours. Finally, the Goddard-Bell-Sandia Collaboration (Barthelmy *et al.* 1988) report a tentative value of $0.81 \pm 0.17 \times 10^{-3}$ photons cm^{-2} s^{-1} for the 1238 keV flux, measured on a balloon flight from Alice Springs on 1988 May 2.

In the present *Letter* we have reported on gamma-ray lines which we associate with the 847 keV and 1238 keV transitions in ^{56}Fe from the radioactive decay of ^{56}Co in SN 1987A. Work on additional lines mentioned in our preliminary reports (Rester *et al.* 1988*a*, *b*) is still in progress.

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